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The Dielectric Resonator

A Miniature Component for Realizing Stable Microwave Oscillators and Microwave Filters

For a few years now, the leading component manufacturers have offered a microwave component that now becomes interesting to radio amateurs due to the reduction in prices: This is the dielectric resonator. The following article is to describe this component and to show what it can be used for.

Only two types of transmit or receive oscillators were used for amateur radio communications in the 10 GHz range: The mechanically, or varactor-tuned Gunn oscillator with cavity resonator for simple, portable equipment, and the crystal-controlled varactor multiplier for home stations. A cavity resonator constructed using amateur methods often does not work satisfactorily, since high Q-values are difficult to obtain, and since the mechanical construction required for frequency tuning and temperature stabilization are very difficult. Also the trend to miniaturization is turning against such types of resonators.

The dielectric resonators, and ready-to-operate components equipped with them, allow one to construct a good transceiver for the 3 cm band relatively easily.

1. THE DIELECTRIC RESONATOR

In its simplest form, a dielectric resonator is a cylindrical disk made from a dielectric having a very high dielectric number ε_r. The electromagnetic fields form standing waves in this dielectric. As is the case with all cavity resonators, these waves represent the frequency-determining resonances, which are dependent on the geometric dimensions, the relative dielectric number ε_r, and the relative permeability number μ_r.

Although a multitude of standing waves, and thus resonances, can form within a resonator we are only going to consider a certain fundamental oscillation caused by the type of excitation in the following article. In the case of a cylindrical disk whose diameter D is approximately twice as large as the height H, the fundamental oscillation will form a wave which is similar to the H_{011}-mode (TE_{011}) of round cavity resonators. The field lines are shown in **Figure 1**.

In the case of a metallic cavity resonator, the

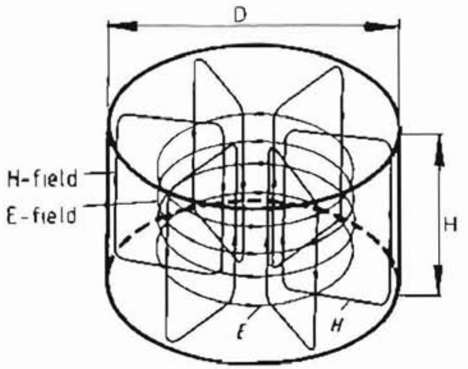

Fig. 1a:
Model of the electrical and magnetic fields of a H_{011}-resonance of a metallic cavity resonator

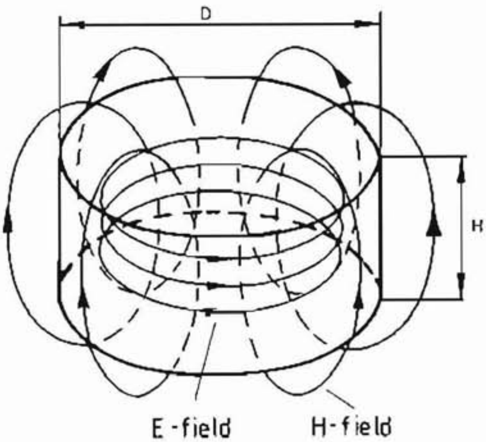

Fig. 1b:
Model of the electrical and magnetic fields of the H_{011} resonance of a dielectric resonator.

conductive walls and the induced currents in the walls form the limitation for the internal fields. Practically speaking, no fields are present outside, and the resonator must be provided with coupling holes, or striplines through the wall in order to be connected to the rest of the circuit. This makes it difficult to use such resonators in stripline circuits.

In the case of a dielectric resonator, the electrical field is concentrated inside the disk due to the high dielectric number. The higher the dielectric number, the better. For this reason, the materials used for dielectric microwave resonators have dielectric numbers between 5 and 150. Since the permeability number is $\mu_r = 1$, the magnetic field will extend outside the resonator in contrast to a metallic cavity type, which allows the dielectric resonator to be coupled to lines relatively easily

The greatest advantage of the dielectric resonator is, however, its compact dimensions. In the case of the H_{011}-resonance of an airfilled resonator, the diameter D corresponds approximately to a wavelength, which means D = 3 cm in the 3 cm band, and H = 1.5 cm. In a dielectric , the velocity factor of the electromagnetic waves is reduced by the factor $1/\sqrt{\varepsilon_r}$, which means that the dimensions of the dielectric resonator can be reduced by the same factor With a dielectric of ε_r = 38.5, as used by us, the resonators for the 10 GHz band will have a diameter of 5 mm and a height of 2 mm.

The quality of such a resonator is determined by its Q, and the temperature stability of its resonant frequency. Both magnitudes are determined by the material, but also by the coupling to the circuit.

Due to the low losses in the dielectric, the non-load Q of available dielectric resonators for the 3 cm band amounts to approximately Q = 5000. The effective operating-Q will be lower due to the coupling to the circuit.

The temperature coefficient of the material is practically negligible since it is $\pm$ 1 x 10^{-6}/K. However, it is possible to adjust it in relatively wide ranges during manufacture, so that a compensation with the temperature response of the circuit is possible. In the case of a negative temperature coefficient of the material, it is possible to compensate for the usual positive temperature response of the circuit so that a virtually temperature-independent oscillator frequency results.

These possibilities are very exciting, but only those radio amateurs can carry out their own experimentations who have access to the corresponding laboratory equipment.

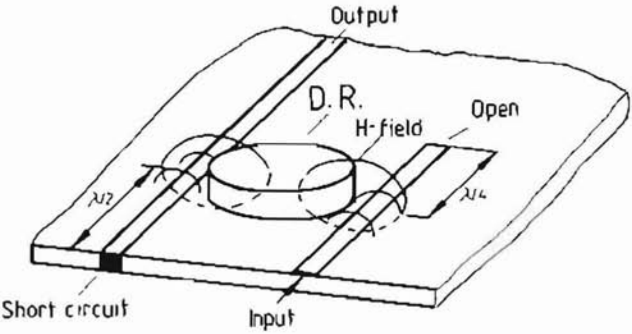

Fig. 2:
Coupling of the magnetic fields of striplines with those of the dielectric resonator

1.1. Coupling the Resonator to the Circuit

Due to the fact that fields – especially the magnetic field – are also present outside the resonator, it is possible for it to be coupled easily to a stripline. As can be seen in **Figure 2**, the resonator is mounted in the vicinity of a stripline so that the magnetic fields can couple between line and resonator. The degree of coupling can be adjusted with the aid of the spacing between line and resonator, which is most easily made with the aid of a PTFE-foil between resonator and the PC-board material of the stripline. The foil will also increase the spacing of the resonator from the metallic ground surface of the stripline, which reduces the heavy current losses due to the resonator field, and will improve the Q.

The coupling to the line is made best at a point of maximum current, which is λ/4 from the end of an open, or λ/2 from the end of a short-circuited line, since the magnetic field is strongest at this position. The matching to the line is made by altering the degree of coupling.

To construct high-quality filters, several dielectric disks can be combined together that are directly coupled to another in a series circuit (1), (2).

1.2. Tuning the Resonant Frequency

The resonant frequency of the dielectric disk is altered on mounting it onto a stripline circuit, since the metallic edge of the ground surface of the stripline PC-board material and the case will limit the fields. This effect is used for tuning the resonator. **Figure 3** shows a drawing of the installation of a dielectric resonator in a metallic cavity. With the aid of the tuning screw, it is possible to reduce the free space over the resonator, which increases the resonant frequency. This method allows one to tune over the whole 3 cm band without difficulties.

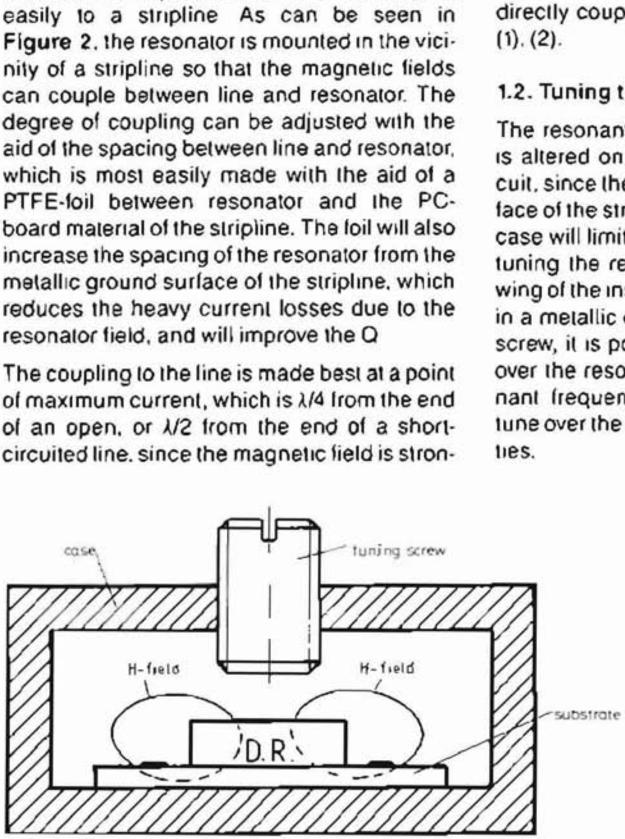

Fig. 3:
Mechanical tuning of the resonant frequency

The disadvantage is that the additional heavy current losses in the tuning screw reduce the operating Q. It is therefore advisable to polish the end of the screw and silver-plate it. A further disadvantage was found in that the temperature coefficient was dependent on the position of the screw. Theoretically speaking, it is most certainly possible to provide a compensation over a wider tuning range, however, this is so difficult in practice that it was not attempted by the authors.

2. DIELECTRIC STABILIZED OSCILLATOR (DSO)

The dielectric resonator with its stable temperature characteristics and its high Q allows the construction of compact, microwave oscillators having a high stability, good efficiency, and low cost. If a GaAs-FET is used as active component, this will result not only in relatively high efficiency but also in a low dependence of the frequency on the operating voltage and load. It is easily possible to achieve a mechanical tuning over a range of more than 500 MHz in the 3 cm band.

Such oscillators have been offered as modules by Mitsubishi since 1981. They are used as security systems at 10.525 GHz and are available at interestingly low prices (3). The doppler module FO-DP 12 KF and the receiver module FO-UP 11 KF were examined to establish their suitability for amateur communications in the 10 GHz band. DB 1 NV constructed a transceiver with the former module that will be described in a later edition of VHF COMMUNICATIONS.

In the case of both modules, the whole circuit

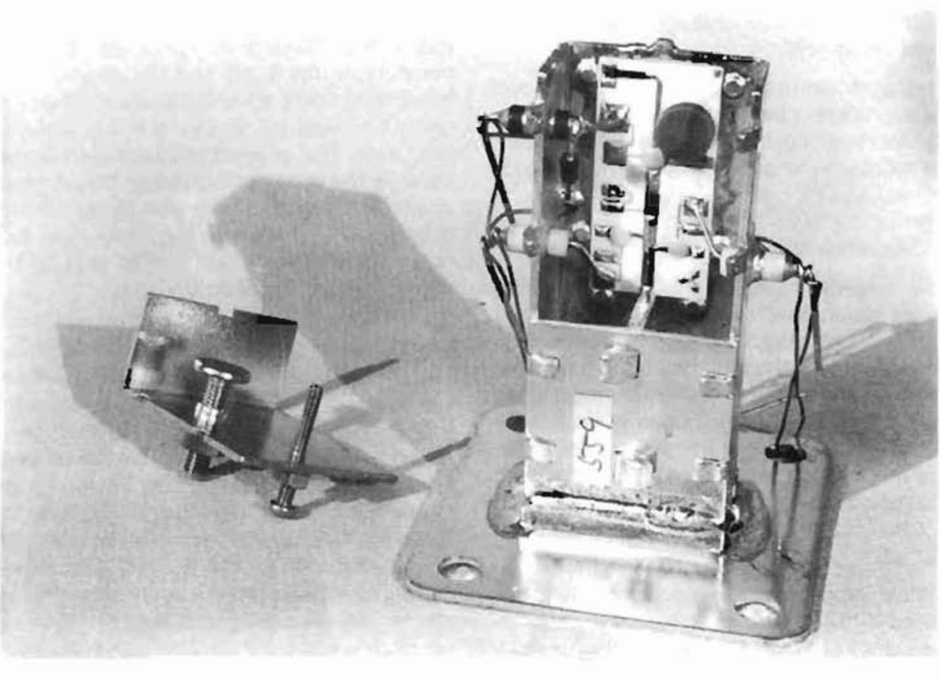

Fig. 4: The construction of a DSO manufactured by Mitsubishi

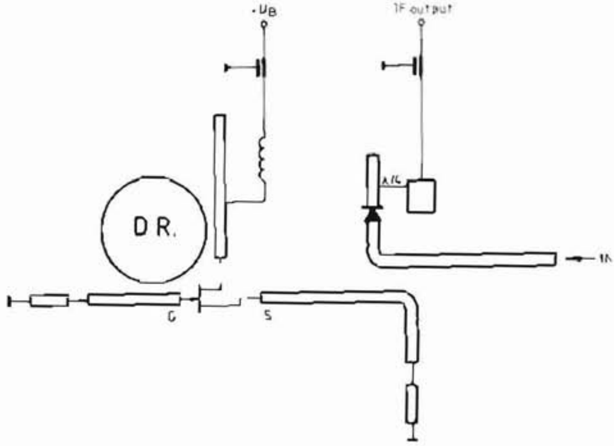

Fig. 5:
Principle circuit diagram of the receiver module FO-UP 11 KF

is realized on a ceramic substrate using a microstripline technology and is directly mounted into a waveguide with flange (**Figure 4**). The operating voltages are fed into the circuit via feedthrough capacitors, as is the IF-signal. A screw is provided for tuning, however, it should be replaced by a micrometer thread if the module is not to be used for a fixed frequency.

Further screws or threaded holes are provided for alignment of the mixer for minimum noise, and for matching, or – in the case of the receiver module – for suppression of the oscillator signal.

2.1. Receiver Module FO-UP 11 KF

The receiver comprises a Schottky diode mixer together with a dielectrically-stabilized FET-oscillator. As can be seen in the circuit given in **Figure 5**, the transistor is fed back from the drain line via the dielectric resonator to the gate line. A directional coupler at the source couples out the oscillator signal and feeds it to the mixer diode, which is also provided with the receive signal. The IF-signal is passed via a $\lambda/4$-choke for microwave frequencies to the output.

In its original state, the receiver module was tuned to 10.465 GHz which results in a receive frequency of 10.525 GHz when using an intermediate frequency of 60 MHz. The tuning screw allowed a frequency variation of the oscillator from 10.15 GHz to 11.4 GHz.

The mixer current was in the range of 2 to 3 mA, and the current drain of the oscillator amounted to 50 mA at U_B = 6 V, which is far less than when using the corresponding Gunn oscillator.

When using an input frequency of 10.360 GHz and an IF of 100 MHz, the conversion loss was measured to be 9 dB, and the double-sideband noise figure of the mixer was 10 dB when using a subsequent receiver with a noise figure of 2 dB. The radiated oscillator level at the input of the mixer amounted to 80 μW and could be reduced to zero with the aid of the tuning screw. This screw also influences the noise figure of the mixer and is aligned for minimum noise in the factory.

In a second module, the oscillator frequency was aligned to 10.514 GHz, and was provided with a subsequent IF-amplifier equipped with a GaAs-dual-gate-FET, similar to that described in (4). **Figure 6** shows the circuit and **Figure 7** gives the gain and DSB noise figure for an intermediate frequency of 135 MHz to 155 MHz. This corresponds to an input signal range of 10.359 to 10.379 GHz. The mixer current for the lowest noise figure amounted to 1.5 mA, and the operating voltage of the receiver module was 6.2 V together with a total current drain including the stabilization, and the IF-amplifier, of 67 mA.

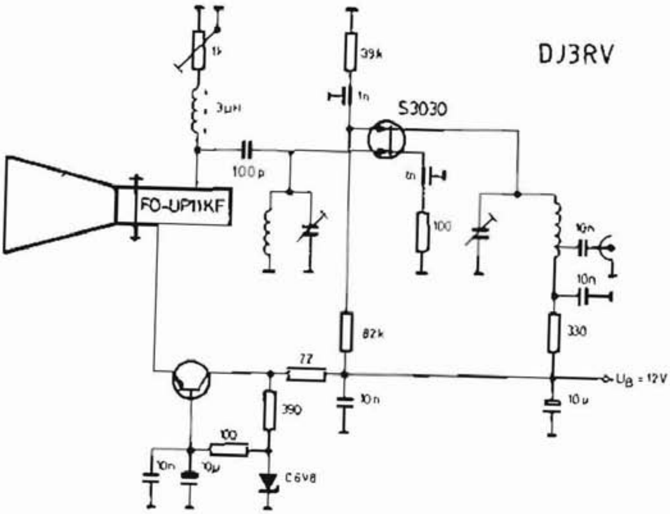

Fig. 6:
Receiver module with amplifier for a 144 MHz IF

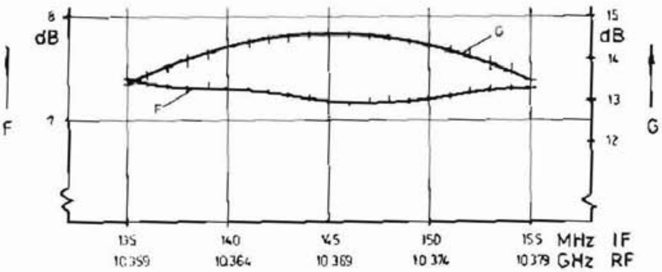

Fig. 7:
Noise figure and gain of the 10.3 GHz receiver module as shown in Figure 6

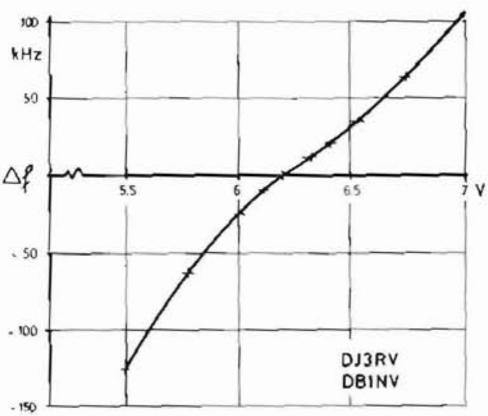

Fig. 8:
Frequency deviation as a function of operating voltage fluctuations

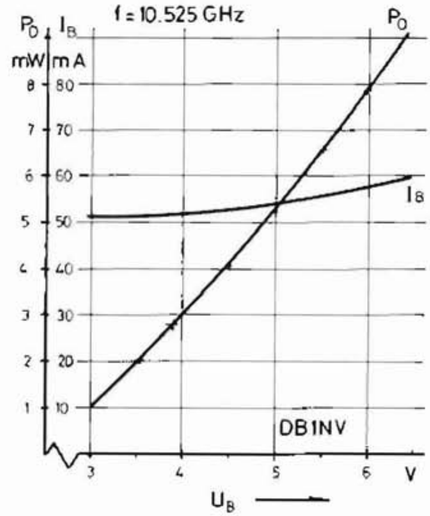

Fig. 9:
Output power and current drain as a function of the operating voltage

In order to determine the frequency stability as a function of the operating voltage, the voltage stabilizer circuit was disconnected and the receiver module was directly driven. As can be seen in **Figure 8**, the measured module was considerably better than the value of 2 MHz/V given by the manufacturer. The diagram shows a slightly positive coefficient, and the deviation can easily be compensated for with the aid of an AFC in the subsequent receiver.

During this measurement, the matching screw was aligned for minimum noise and it was determined by chance that the frequency behaviour became worse to the value of approx. −400 kHz/V when aligning for minimum oscillator radiation, and this led to negative coefficients. This is a further reason why one should not align the matching screw at random.

The typical temperature drift is given by the manufacturer as 10 MHz in a range of −30°C to +70°C which corresponds to an instability

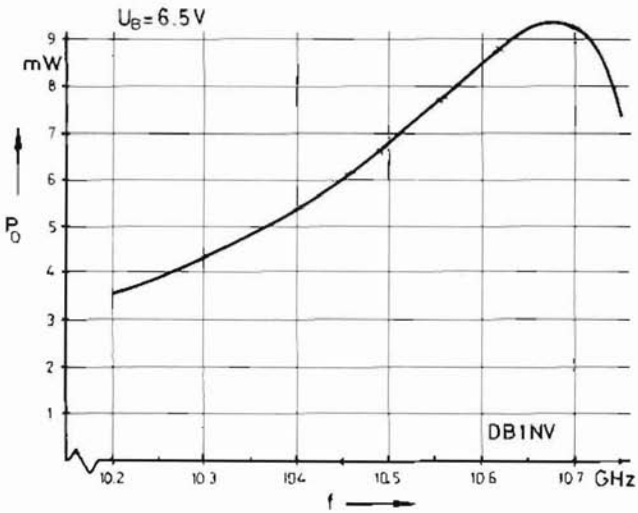

Fig. 10:
Output power as a function of frequency

of 100 kHz/°C. Measurements made in a test chamber at 0°C and +40°C showed a frequency variation of −1.2 MHz, which shows that this value is considerably better than specified for the original frequency. If, on the other hand, one detunes the oscillator frequency, this will have a negative effect on the temperature behaviour! Exact measurements were not carried out, since the oscillator tuning screw was first to be replaced by a micrometer thread.

2.2. The Doppler Module FO-DP 12 KF

The doppler module was designed for determining moving objects in security systems. It operates according to the principle of a straight-through mixer. The transmit signal is used simultaneously for converting the receive signal, in the same manner as when using the wellknown "Gunnplexer". The doppler module is to be used for the same type of operation, and it is interesting to know the output power, frequency stability, and the tuning range characteristics.

Figure 9 gives the output power and current drain as a function of the operating voltage. A further module was used at the original frequency and at the recommended operating voltage of U_B = 6.5 V recommended by the manufacturer. It provided an output power of 13 mW at a current drain of 44 mA.

One will notice the high efficiency of the oscillator with respect to Gunn diodes; the power requirements are approximately only one third that of a Gunn oscillator of the same power.

Unfortunately, the output power is very dependent on the output frequency, as can be seen in **Figure 10**. In the amateur band in the order of 10.35 GHz, at least 4 mW RF-output power was available, which could be increased to 7 mW when using a matching transformer between module and antenna. Attention should be paid that the mixer diode current does not drop considerably, since the conversion loss will then increase to impermisssible levels. For this reason, the manufacturer recommends that the mixer diodes are operated with a bias current of approximately 1 mA.

The stability of the output frequency with respect to operating voltage fluctuations is better than 200 kHz/V; the frequency can be shifted by a maximum of 800 kHz by load reflections. The frequency drift as result of temperature is negligible when compared with resonator-controlled Gunnplexers.

The high frequency stability of the DSO makes it virtually impossible to use the conventional type of modulation or fine tuning with the aid of the operating voltage. However, it allows the AFC-operation to be made at IF-level, which simplifies the circuit.

As can be seen in the photograph given in Figure 4, the doppler module is provided with two mixer diodes, which can be used for modulation. One feeds in a constant current and the AF-signal is coupled in capacitively.

Since the doppler module is used in the transceiver constructed by DB1NV, as has been previously mentioned, the operation can be studied there in more detail.

3. REFERENCES

For those readers that want to read more on dielectric resonators, we would like to recommend the following articles (1) and (2):

(1) J. K. Plourde, C.-L. Ren:
Application of Dielectric Resonators in Microwave Components
IEEE Trans. MTT, Vol. 29, No. 8, P 754-770

(2) K. Pöbl, G. Wolfram:
Dielektrische Resonatoren, neue Bauelemente der Mikrowellentechnik
Siemens Components 20 (1982)
Edition 1, pages 14 – 18

(3) Microwave GaAs-FET's Modules
Stabilized Oscillators and Sensor Modules
Mitsubishi Electric Corp., Tokyo